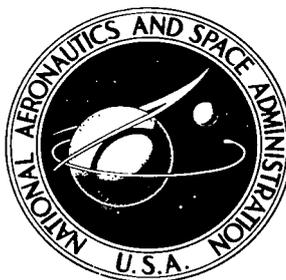


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PARALLEL GAP WELDING KOVAR RIBBONS TO COPPER CONDUCTOR PRINTED WIRING BOARDS

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16. Abstract <p>This report describes an investigation to determine the feasibility of, and to subsequently develop the quality assurance criteria for parallel gap welding Kovar ribbons to copper conductor printed wiring boards. The investigation included preliminary screening tests considering several copper conductor sizes (thicknesses and widths), plating combinations (types and thicknesses), and ribbon sizes. Several successful combinations were derived which were explored in greater depth.</p> <p>Results showed that parallel gap welding Kovar ribbon to copper conductors is feasible but is highly dependent upon the overplating type and thickness.</p>			
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PARALLEL GAP WELDING KOVAR RIBBONS TO COPPER CONDUCTOR PRINTED WIRING BOARDS

SUMMARY

Because of interconnection problems in aerospace electronics fabrication associated with conventional soldering techniques, parallel gap welding of Kovar ribbons to copper conductor printed wiring boards was investigated. Resistance and corrosion barrier platings were required to overcome the thermal and electrical conductivity and melting point mismatch between the Kovar ribbon and copper conductor.

The investigation was conducted in two phases. Preliminary screening tests considered several copper conductor sizes, plating combinations, and Kovar ribbon sizes. From the tests, several successful combinations were derived which were explored in greater depth in the second phase of the effort.

The investigation showed that parallel gap welding of Kovar ribbons to copper conductor printed wiring boards is feasible. Success is dependent on the type of plating/coating over the copper conductors, but is not particularly dependent on the ribbon and conductor size combinations. Optimum combinations for welding are gold-plated Kovar ribbons to solder coated/plated (500 to 1000 microinches thick) copper conductors.

In addition to the investigative results presented in this report, quality assurance and inspection criteria were developed from the knowledge acquired and are contained in this report. This quality criteria can thus serve as basic guidelines for the development of manufacturing processes.

SECTION I. INTRODUCTION

Presently, the most widespread method used by the electronic industry for joining component leads to connection pads on printed wiring boards is soldering. However, in the past, numerous system failures have been pinpointed to electrical discontinuities caused by cracked solder or by complete solder separation from associated copper pads. This project was undertaken in an attempt to produce a reliable connection for specialized needs between Kovar ribbons of flat-pack electronic packages and copper conductors of printed wiring boards. To produce such a reliable connection, its strength must be increased to approach the strength of the weaker material being joined.

Varying environmental conditions require more reliable connections than the soft soldering technique has provided. Some of these printed wiring board environmental parameters that require higher connection strengths are: Rapid compression and decompression, thermal expansion differentials, rapid vacuum reduction, high vibration, and high temperature. All of these conditions place undue stresses upon interconnections, and when the strength of the interconnects is insufficient, electrical discontinuity is induced.

Parallel gap welding is known to provide high interconnection strength when wiring boards of nickel or Kovar cladding is used. This is not always feasible because of the inherent ferromagnetic properties of these materials when used as a conductor [1]. This would be detrimental in RF circuitry applications in which frequency shift losses and increased signal couplings cannot be tolerated. Nickel or Kovar-clad printed wiring boards are more difficult to fabricate, are less available, and thereby are more costly. The high resistivity also causes them to be unsuitable for some applications.

Because copper-clad printed wiring boards are readily available, reasonably priced, and do not have some of the disadvantages stated above, they were investigated in this project. However, bare copper is highly conductive and susceptible to oxidation and corrosion. Therefore, gold, nickel, and solder platings were selected for use. These platings were designed to serve as a resistance barrier to current flow between Kovar and the highly conductive copper as well as to protect the copper against oxidation and corrosion. The solder acts as a higher resistance to the flow of the direct current than gold or nickel. When molten, the solder then becomes depleted at the Kovar-copper interface by the electrode force during the welding cycle. This causes a brazing of these materials and results in a highly electrically conductive and reliable connection.

This report discusses materials used with and without plating barriers, equipment, weld parameters, weld schedule development, pull test, and metallographic examination results. Also, quality and inspection requirements are discussed.

SECTION II. PURPOSE AND OBJECTIVE

In an attempt to enhance quality and subsequent reliability by achieving a stronger Kovar ribbon to copper conductor printed wiring board interconnection, parallel gap welding was investigated as the attaching media. This investigation proves the feasibility, establishes some successful combinations of Kovar ribbon and copper conductor sizes and plating conditions, and evolves the general quality assurance and inspection criteria for the technique.

SECTION III. LITERATURE SURVEY

A literature survey of parallel gap welding revealed that numerous evaluation programs were conducted in the United States and in Great Britain. Interest has appeared to be centered toward providing another interconnection technique in addition to soft soldering, one with inherently improved interconnection reliability.

The results of the studies surveyed varied widely and were not in full agreement as to Kovar-to-copper weldability. W. H. Hill [2] states that satisfactory welds are produced when welding to copper but that the tolerances are narrow. N. Jarosik [3] states that copper and Kovar combination welds are unacceptable. The use of barrier platings was investigated by H. G. Carter and W. W. Wilson [4]. In their development of a more economical weldable printed wiring board, they state that chemically deposited nickel plating over copper resulted in simple welding, inexpensive board material, and acceptable weld reliability.

Even though test results vary, the studies are in agreement by inference that material process controls and weld system parameter selections and controls are important factors in the achievement of improved weld results by the parallel gap welding technique.

SECTION IV. MATERIALS AND EQUIPMENT

A. Materials

The welding of two materials is ideally achieved when the melting points and thermal and electrical conductivity values are reasonably matched. For a selected energy level, the amount of current flowing through a material is dependent upon its electrical conductivity.

The amount of temperature developed and whether melting occurs are dependent upon the thermal conductivity and melting point of a material. Table 1 lists the important properties of metals and alloys used in this investigation. The barrier platings and coatings discussed below are selected to approximate a match between the properties listed in Table 1.

1. Ribbon Material. Ribbon material used with hard glass hermetic seals is of iron-nickel-cobalt composition and is referred to by trade names of Kovar or Rodar. It will be referred to in this report as Kovar. All ribbon material was gold-plated. The plating thickness was controlled between 95 to 125 microinches. The lead dimensions used were confined to the following sizes (in inches):

- a. 0.004 thick by 0.012 wide.
- b. 0.005 thick by 0.015 wide.
- c. 0.007 thick by 0.020 wide.

TABLE 1. PROPERTIES OF METALS/ALLOYS INVOLVED
IN WELDING KOVAR TO COPPER

Metal/Alloy	Melting Point (°C)	Thermal Conductivity (cal/cm ² /cm/sec/°C)	Electrical Conductivity (% IACS ^a)
Copper	1083	0.94	100
Gold	1063	0.71	73
Nickel	1453	0.22	16
Solder (63 Sn-37Pb)	183	0.12	12
Kovar (53Fe-29Ni-17Co)	1450	0.046	3.5

a. IACS – International Annealed Copper Standard

2. Printed Wiring Boards. The initial phase of the evaluation included printed wiring test boards clad with the 2- and 1-ounce copper conductors over G-10 laminate. The same sizes were used on boards of both claddings except as noted. Subsequent effort restricted the conductor width and expanded the laminate types and platings as noted in Section VI. The conductor widths below are in inches.

- a. 0.016.
- b. 0.020.
- c. 0.024.
- d. 0.028 (1-ounce cladding only).
- e. 0.040 (2-ounce cladding only).

The copper conductor plating conditions were as follows:

- a. Bare.
- b. Gold plated.
- c. Gold-over-nickel platings.
- d. Hot dip-tinned 63/37 tin-lead solder. The hot dip-tinned coating was applied by dipping the test boards into the solder pot containing high purity of 63 percent tin and 37-percent lead solder.
- e. Electroplated 63/37 tin-lead, hot oil fused.

B. Equipment

1. Welding System. The welding system used was the Model 1-124-02 Power Supply and Model 2-127-02 Weld Head manufactured by the Weldmatic Division of the Unitek Corporation.

a. Power Supply. The solid-state power supply possessed the capability of pulse control adjustment from 1 to 40 milliseconds in width. A maximum of 2.0 volts amplitude is possible and is dependent upon the pulse-width range selection. This power supply was equipped with manual and/or automatic pulse-width control selection. The manual control mode was used throughout this program to better observe the welding behavior at definite selected parameters.

b. Weld head. The weld head was equipped with electrode holders capable of adjusting the electrode gap tolerance to the nearest 0.001 inch with a micrometer type control. Electrode force variations are readily accomplished from 0.5 to 8.0 pounds. Electrodes RWMA No. 2, size 0.015 by 0.050 inch were used throughout the program.

2. Pull Tester. The pull tester was equipped with a dial-indicating type force gage with readout in pounds and graduated in tenths of a pound. A "hold at maximum" feature allows the operator to record pull-test results when convenient. A moveable clamping table holds a specimen and travels at a fixed rate of 3.5 inches per minute away from the stationary recording force gage until the pull test is completed. The pull tester used in this investigation was a Unitek Model 6-092-01.

3. Metallography Equipment. The metallograph used was the Bausch and Lomb Research Model. Complementary equipment included a specimen cutoff machine, specimen polishers, a vibropolisher, zoom microscopes, and other equipment normal to a fully equipped metallographic laboratory.

SECTION V. WELD TEST PROCEDURES

A. Material Preparation

It is of paramount importance in parallel gap welding to use clean materials to achieve good bonding repeatability. Any dirt or contamination of material surfaces change the resistance at the materials' interface in the weld area and produces a weak weld or no weld depending upon the degree of contamination. Therefore, all materials were cleaned with an ethyl alcohol-saturated, lint-free tissue just prior to welding. In addition, the bare copper test boards were first chemically cleaned to remove oxides, then subjected to the alcohol-tissue cleaning process. Plating measurements were metallographically verified of each plating thickness and type on all printed wiring boards used in the program. Initial measurement of the gold-plated Kovar was made from one lot that was subsequently used throughout the program. The approximate thicknesses of the platings were as follows (in microinches):

1. Kovar ribbon gold plating – 100.
2. Copper conductors.
 - a. Gold -- 100.
 - b. Nickel.
 - (1) 250 (preliminary screening tests only).
 - (2) 500 (final qualification tests only).
 - (3) 1000 (final qualification and preliminary tests).
 - (4) 1500 (final qualification tests only).
 - c. Hot dip-tinned solder – 750 (preliminary screening tests only).
 - d. Electroplated, hot-oil fused solder (final qualification test only).
 - (1) 500.
 - (2) 750.
 - (3) 1000.

B. Weld Parameters

The proper amount of heat and its distribution required to repeatably produce sound welds are dependent upon the following parameters:

1. Pulse amplitude (voltage) -- Selection of pulse amplitude controls the amount of weld current.
2. Pulse duration (time) -- Controls the length of time (milliseconds) during which voltage is applied to aid in proper heat distribution.
3. Gap -- The air space or dielectric between the electrodes. Varying the gap width controls the resistance between the electrodes.
4. Electrode force -- The electrode force holds the ribbon material in place during the weld cycle and also controls somewhat the resistance at the interface of the materials being welded.

C. Weld Schedule Development

The initial weld schedule development investigation revealed that it was necessary to restrict the weld current flow through the highly conductive copper. By decreasing the electrode gap width to the thickness of the Kovar ribbon, more weld current passed through the Kovar and less through the copper, thus providing better heat distribution at the materials' interface. This resulted in more consistent welding.

An initial electrode force of 1.5 pounds resulted in erratic welding. This erratic welding was attributed to possible surface irregularities and variations in plating densities producing interfacial resistance variations. Increasing the electrode force minimized this undesirable condition whereby more consistent weld quality was obtained. This force was finally optimized at approximately 4.0 pounds and used throughout the program.

By standardizing the electrode gap width to the ribbon thickness and the electrode force to 4.0 pounds, the only variables remaining were pulse amplitude and pulse duration. For welding bare copper, gold-plated copper, and gold-over-nickel plated copper, the 1- through 10-millisecond pulse duration range was used. For welding hot dip-tinned copper and electroplated solder on copper, the 2- through 20-millisecond pulse duration range was selected. The following step-by-step procedure was used to establish pulse amplitude and duration values for each material combination:

1. Initially set the pulse amplitude at minimum and the pulse duration at maximum.

2. Incrementally increase the pulse amplitude and perform the welding until a darkened area of the gold plating of the Kovar lead is observed in the gap between the electrodes.

3. Begin pull testing the welded specimens and record the average of five welds at each selected amplitude increment.

4. Continue increasing the amplitude and pull testing the welds until a visually discrepant weld condition is observed.

5. Reduce the pulse duration by selected increments and pull-test welds until the weld separates.

During the preliminary screening tests (Section VI), the pull tests were performed in the lap-shear configuration; however, during the final qualification tests (Section VII), a 180-degree peel-pull test was performed. During the preliminary screening tests, metallographic examinations revealed excessive copper melting on visually-acceptable welds which was not detectable by the lap-shear test; however, the 180-degree peel-pull test revealed the excessive copper melting.

SECTION VI. PRELIMINARY SCREENING TESTS

The preliminary screening tests were designed to determine if parallel gap welding of Kovar ribbon to copper conductors was feasible, and to establish some successful combinations of ribbon and conductor sizes and plating conditions for the purpose of further effort to establish quality requirements for this technique. The preliminary screening tests did not presume to fully consider all possible combinations but did establish a systematic approach to the derivation of successful combinations. An overall evaluation of the test results during this portion of the program is presented in Table 2. This table depicts the various material sizes and copper conductor conditions used in this investigation. Performance of the various combinations are discussed in greater detail in the following paragraphs.

A. Kovar Ribbons Welded to 2-Ounce Copper Conductors

1. Bare Copper. Narrow parameter tolerances were encountered when establishing weld schedules for bare copper. Even after a weld schedule was established, discrepant conditions such as blowholes and excessive copper melting occurred during verification of these weld schedules. Average pull strengths of bare copper welds are also lower than the average weld strengths of the other conductor conditions. A transverse cross-section of a welded connection, Kovar ribbon size 0.004 by 0.012 inch welded to 0.040-inch-width

TABLE II. PRELIMINARY SCREENING TEST RESULTS

Ribbon Sizes (in.)	Conductor Sizes (in.)	Conductor Conditions							
		2-Ounce				1-Ounce			
		Bare	Gold	Nickel	Tinned	Bare	Gold	Nickel	Tinned
0.004 by 0.012	0.016	ER	✓	EC	✓	X	X	X	✓
		EC							
	0.020	ER	ER	EC	✓	X	X	X	✓
		EC							
	0.024	ER	✓	1000 200 μ in. μ in. EC	✓	X	X	X	✓
		EC							
	0.028	//////	//////	//////	//////	X	X	X	✓
0.005 by 0.015	0.040	EC	EC	EC	✓	//////	//////	//////	//////
		-							
	0.020	ER	ER	EC	✓	X	X	X	✓
		EC							
	0.024	ER	EC	EC	✓	X	X	X	X
		ER							
	0.028	//////	//////	//////	//////	X	X	X	✓
0.007 by 0.020	0.040	ER	ER	ER	✓	//////	//////	//////	//////
		ER							
	0.024	ER	ER	EC	✓	X	X	X	✓
		ER							
	0.028	ER	ER	EC	✓	X	X	X	✓
		EC							
	0.040	ER	ER	EC	✓	//////	//////	//////	//////

NOTES: ✓ = Acceptable (visual and metallurgical).
 EC = Excessive copper heating.
 //// = Not programmed.

X = Not conducted because of overall unsatisfactory performance on 2-ounce conductor.

ER = Erratic welding.

bare copper conductor, is shown in Figure 1 and exhibits a condition of excessive copper melting. During pull tests of this size combination, the Kovar ribbon broke some distance

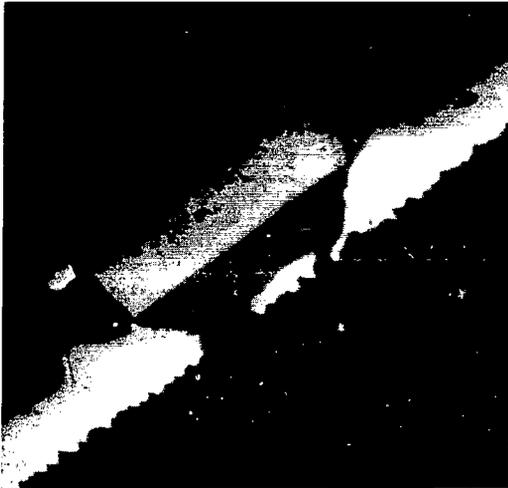


Figure 1. Kovar ribbon welded to bare copper conductor (135X)

away from the weld in every case. Pull-test results of other size combinations of this conductor condition ranged in strength from approximately 1.2 pounds (with weld separation) to the tensile strength of the ribbon or the copper conductor. Visual observations revealed considerable copper melting in some welds, which occurred for no apparent reason, and invariably resulted in blowholes in the copper conductor while other welds were visually evaluated as acceptable and verified through metallographic examinations.

2. Gold-Plated Conductors. Welding of Kovar ribbons to gold-plated conductors produced more consistent and greater weld strengths than to the bare copper conductors. Visual appearance was also of acceptable quality. However, metallographic investigation revealed numerous voids at the ribbon conductor interface but a smooth fillet at

each side of the Kovar lead-conductor interface. A photomicrograph of Kovar ribbon (0.005 to 0.015 inch) welded to a gold-plated copper conductor 0.024-inch wide is shown in Figure 2. Similar discrepant weld conditions were noted when other size combinations were welded and metallographically investigated.

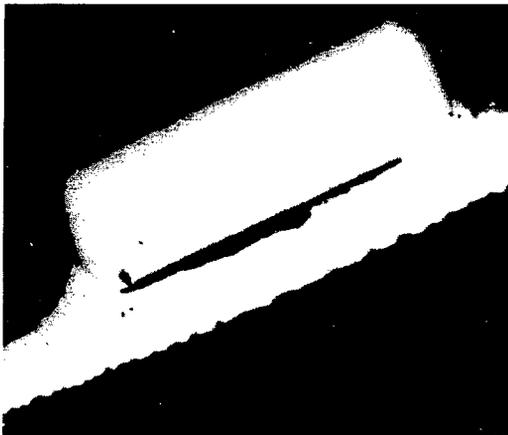


Figure 2. Kovar ribbon welded to gold-plated copper conductor (135X)

3. Gold-Over-Nickel-Plated Copper Conductors. Normal nickel-plating thickness was approximately 250 microinches with a gold plating of approximately 95 to 125 microinches over the nickel. Visual examination of the welds revealed discrepant-free surface conditions. The welds displayed a smooth darkened gold band between the electrodes. However, metallographic examination revealed considerable variation in the condition of the copper at the weld zone as is contrasted in Figures 3 and 4. Both connections were welded using the same parameters and were visually acceptable. These photomicrographs are of 0.004- by 0.012-inch Kovar ribbon welded to 0.024-inch-wide gold-over-nickel-plated copper



Figure 3. Acceptable weld connection of Kovar ribbon to gold-over-nickel-plated copper conductor (135X)

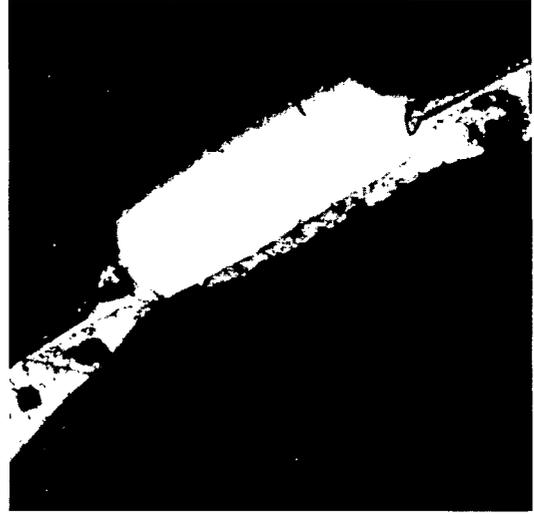


Figure 4. Discrepant weld connection (copper melting) using same conditions as Figure 3 (135X).

conductor. Gold-over-nickel plating of about 1000 microinches of the same size combination produced welds that were visually and strengthwise comparable to those with normal plating thickness. Metallographic examination also revealed a discrepant-free bond identical to that shown in Figure 5. The excellent quality of the weld is quite evident. Only one size of Kovar ribbon-to-copper conductor combination with the heavy nickel plating was evaluated.

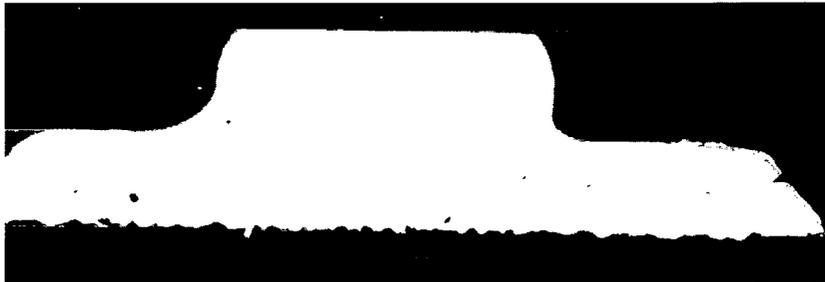


Figure 5. Weld connection of Kovar ribbon to gold-over-heavy-nickel-plated copper conductor (135X).

4. Hot Dip-Tinned Copper Conductors. This condition exhibited the highest quality of welds. Weld schedules of all size combinations were verified by subsequent metallographic examinations. All cross-sectioned welds revealed discrepant-free acceptable welds. A typical weld of Kovar ribbon (0.005 by 0.015 inch) welded to 0.040-inch-wide hot dip-tinned copper conductor is shown in Figure 6. Note the slight copper erosion on each side of the Kovar. A portion of the weld of this connection is depicted at higher magnification in Figure 7 and shows a brazed alloy at the Kovar-copper interface. The eroded portion at the side of the Kovar is also shown at higher magnification in Figure 8. This erosion can be attributed to the hot molten solder being expelled from under the Kovar ribbon by the force of the electrodes as the weld energy is released during the weld cycle. This erosion was observed in all of the metallographically investigated Kovar ribbon to hot dip-tinned copper conductor weld specimens.

B. Kovar Ribbons Welded to 1-Ounce Copper Conductors

The overall quality of welded connections of a Kovar ribbon and a 1-ounce copper conductor was generally unsatisfactory. Otherwise acceptable connections displayed bending or settling of the copper. Performance of the various combinations are discussed in greater detail in the following paragraphs.

1. Bare Copper Conductor. This conductor condition was not welded with repeatable satisfactory results on 2-ounce conductors; therefore, only one size combination (0.007 by 0.020 with Kovar ribbon and 0.028-inch-wide copper conductors) was investigated. This also yielded unsatisfactory results.

2. Gold and Gold-Over-Nickel-Plated Copper Conductors. Again, these platings did not resolve the excessive copper conductor melting problem confronted during welding with the 2-ounce copper conductors; therefore, only one size combination (0.007 by 0.020 Kovar ribbon and an 0.028-inch-wide copper conductor) was investigated. As expected, the results were unsatisfactory.

3. Hot Dip-Tinned Copper Conductors. Tests were completed for all scheduled size combinations. Visual inspection revealed no discrepant weld conditions. Metallographic examinations showed that the bonded interface was of a similar acceptable condition as the 2-ounce conductors. However, there appears to be a tendency for the 1-ounce copper conductors to settle more under the Kovar ribbon than the 2-ounce copper conductors. A most severe case of this condition is shown in Figure 9 where an 0.004- by 0.012-inch Kovar ribbon was welded to 0.028-inch-wide hot dip-tinned copper conductors.

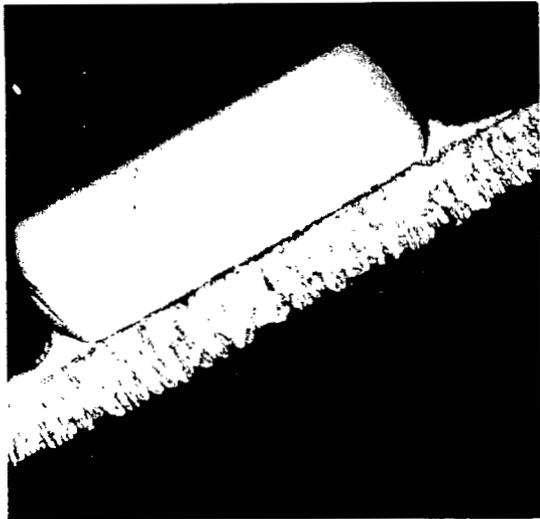


Figure 6. Kovar ribbon welded to a tinned copper conductor (135X).

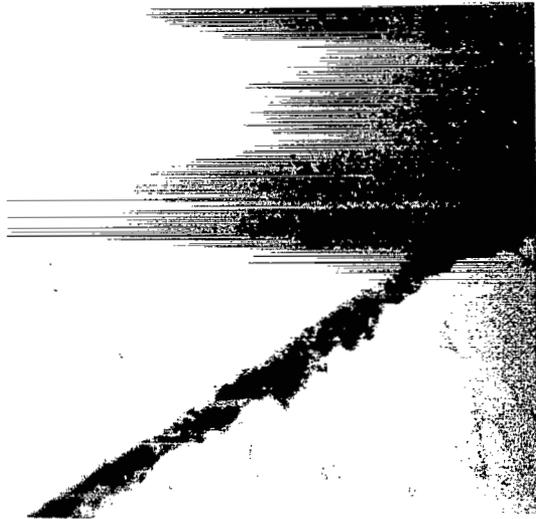


Figure 7. Higher magnification of the interface in Figure 6 (893X).



Figure 8. Typical copper erosion along the length of a Kovar ribbon (893X).

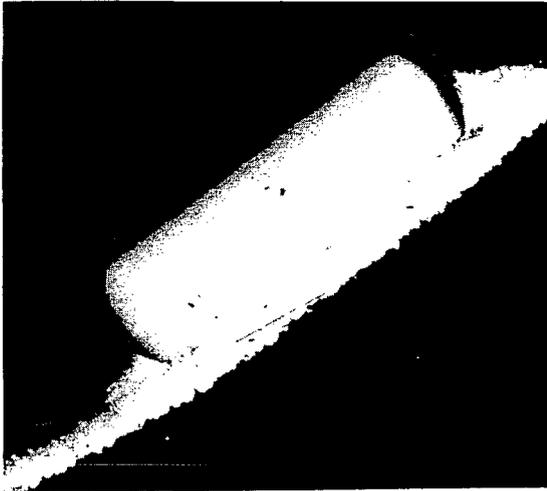


Figure 9. Settling of the copper conductor under a Kovar ribbon (135X).

C. Summary of Test Results

The summarized tests results are as follows:

1. It is quite evident, as shown by the test results in Table 2, that welding to bare copper produces considerable variation in the quality of the welds. These ranged from acceptable welds to complete blowout of the copper in the electrode gap area which can go undetected during visual inspection.

2. Conductors plated with a gold-over-heavy-nickel plating exhibited all criteria of acceptable welding both during visual and metallurgical examination.

3. Welded Kovar ribbon to hot dip-tinned copper conductor repeatedly produced discrepant-free connections.

4. Discrepant conditions such as blowholes or excessive copper melting did not appreciably affect weld pull strengths during preliminary screening tests. Therefore, a 180-degree peel-pull configuration was used during the final qualification tests. This type test can better reveal any copper melting or other discrepant conditions existing at the conductor-laminate interface.

SECTION VII. FINAL QUALIFICATION TESTS

Tests performed during the preliminary screening tests revealed a similarity of weld results regardless of size combinations welded. Therefore, only one size combination was selected for final qualification tests. However, a greater selection of plating thicknesses, over 2-ounce copper conductors, was chosen. This approach was taken to better determine minimum plating thicknesses that can be tolerated when welding Kovar ribbons to copper conductors. Also, two additional types of base laminates were added to determine what effects the different laminates have, if any, upon the weld quality. The various test combinations and their performance are discussed in the following paragraphs.

A. Test Combinations

1. Kovar Ribbon Material. The Kovar lead material was gold-plated (0.005 by 0.015 inch). The gold-plating thickness was approximately 100 microinches thick.

2. Printed Wiring Test Boards. The copper conductors were all 0.024-inch wide on G-10, FR-45, and Micarta laminates. These laminates were used to determine whether the welding heat affects them similarly. The platings and plating thicknesses (in microinches) over the copper conductor of each laminate were as follows:

a. Nickel, Gold Over Plate.

- (1) 500.
- (2) 1000.
- (3) 1500.

A nickel sulfamate bath solution was used for nickel plating. The nickel was overplated with gold, approximately 100 microinches thick to preclude nickel passivation.

b. Electroplated Hot Oil Fused Solder.

- (1) 500.
- (2) 750.
- (3) 1000.

The solder platings were fused in peanut oil at 500°F. This was performed to reveal any contaminated copper surfaces which would cause dewet of the solder and to preclude copper oxidation.

B. Test Results

1. General. Acceptable welds were produced repeatedly when welding to electroplated, hot-oil fused solder, copper conductors. All three laminates, G-10, FR-45, and Micarta, showed similar surface conditions in the heat-affected zone.

2. Plating Effects. Plated nickel thickness of approximately 500 microinches did not produce consistently discrepant-free welds. During the qualification of the weld schedule, visible blowholes were noted in the conductors; therefore, this thickness was established as unqualified for parallel gap welding. Nickel-plated thicknesses of approximately

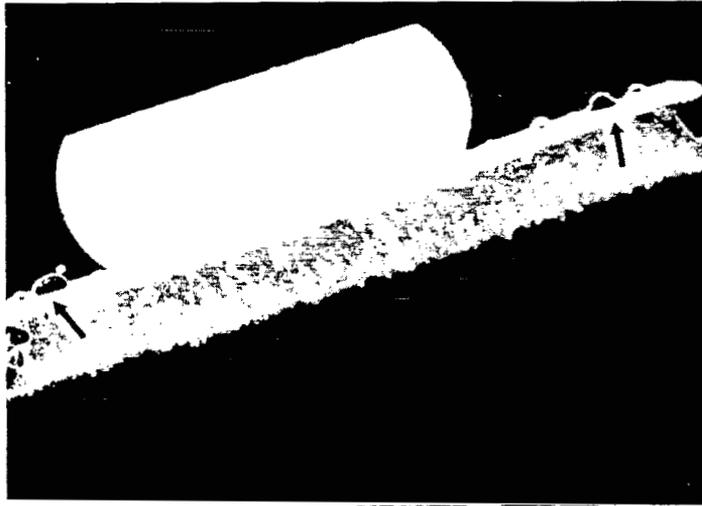
1000 and 1500 microinches produced visually acceptable welds. However, when metallographically examined, the gold plating used to prevent nickel passivation showed signs of buckling when subjected to weld heat. In addition, voids were seen in the weld zone. These two unacceptable conditions may be attributed to the outgassing of the occluded organic materials used in the plating solutions. Representative examples of this condition encountered are pinpointed in photomicrographs A and B of Figure 10. Note the gas pockets under the buckled gold plating. The electroplated, hot-oil fused solder appears to lend itself favorably to parallel gap welding of Kovar ribbons to copper conductors.

3. Peel-Pull Tests. Peel-pull tests revealed that the copper conductors did not break in a uniform line across the welded connection but followed interfacial bonding. In some instances, the break was uniform across the weld as the ribbon was peeled off. An example of peel-pull-tested specimens is shown in Figure 11. No appreciable difference in the tearing mode was noted between nickel- and electrosolder-plated conductors. The copper conductor pinpointed by one arrow shows its rather uniform breaking mode. The copper conductor identified between the two arrows shows an irregular tearing effect. This irregular tearing of the copper conductor resulted in the observed peel-pull strength variations.

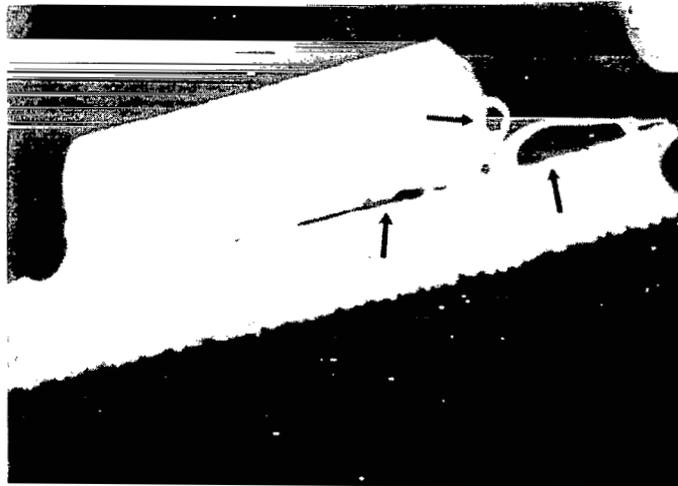
For each plating condition and plating thickness over copper conductor of each laminate, a qualification test was conducted. This consisted of welding a total of 50 connections of each category and subjecting them to peel-pull tests. In only one case was the peel strength below 1 pound (0.8). Four other welds separated but were comparable in strengths to those in which either the Kovar ribbon or copper conductors broke. All five weld separations were in the 1000-microinch plated-nickel thickness category.

A summary chart of weld test results is given in Table 3. It presents the average strength of each plating condition, plating thickness, and laminate materials. The weld range is also shown for each category by the length of each bar. Even though the maximum values for nickel plating are generally higher than for electrosolder plating, the minimums are lower for nickel in all cases except one. Even the lowest pull strength of 0.8 pound (approximately 13 ounces) is considerably greater than parallel gap soldered connections which showed minimum strengths of approximately 2 to 3 ounces, using similar material size combinations [5]. The visual appearance of the welds are similar to the welds of Kovar ribbon to Kovar conductor connections.

4. Metallographic Examinations. Metallographic examinations were performed on welds of all plating conditions and thicknesses. All three laminates were investigated for copper conductor separation from the laminates or any other gross deleterious discrepancy that could be used as criteria for not approving the laminate for parallel gap welding. Since welds of the 500-microinch, nickel-plating thickness did not qualify during the qualification tests, this group was excluded from the metallographic investigation.



(a)



(b)

Figure 10. Gas pockets, produced at the gold-nickel-plating interface (135X).

TABLE 3. WELD SUMMARY CHART

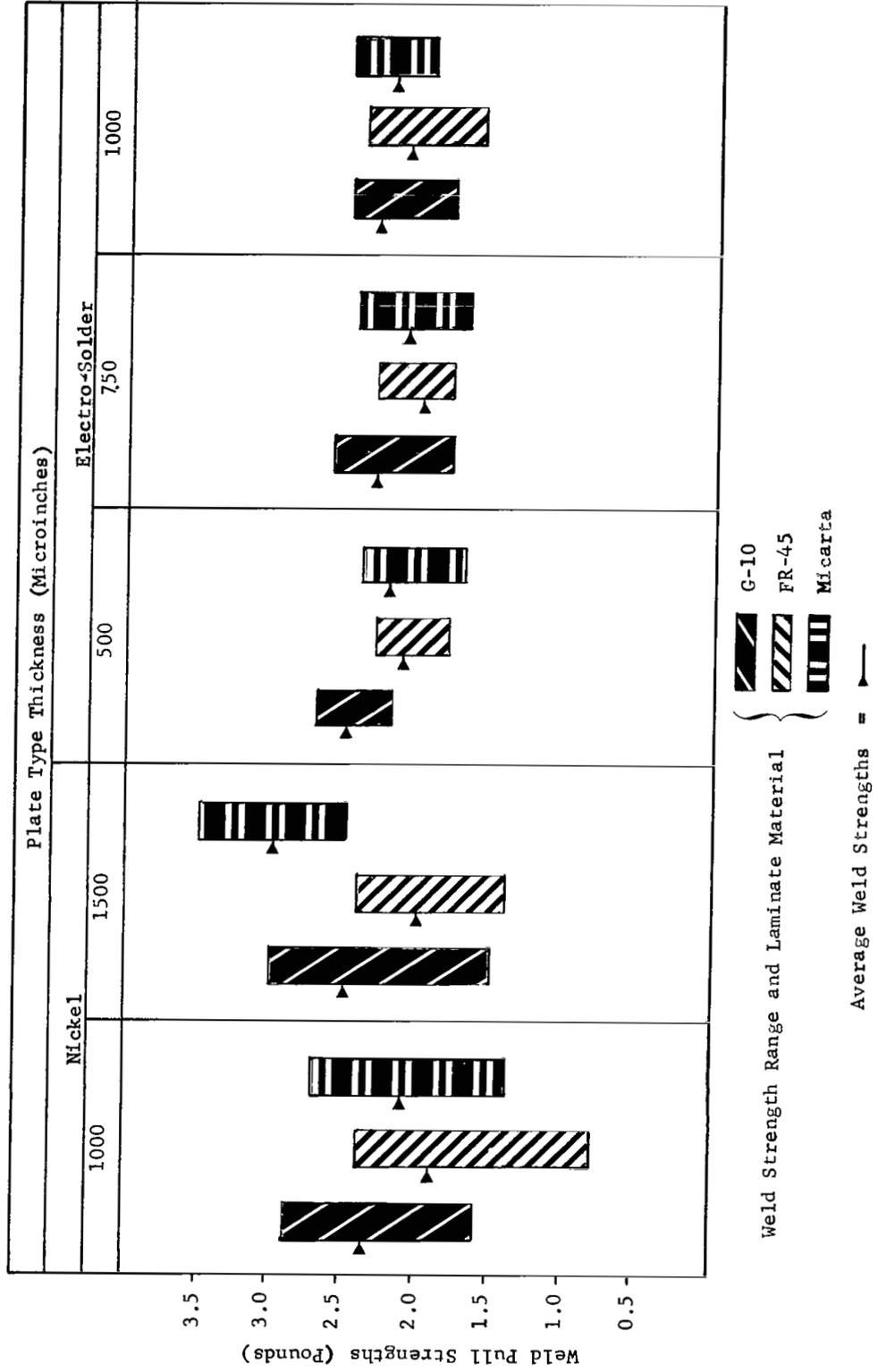




Figure 11. Pull-tested samples of electro-solder-plated copper conductors (15X).

A photomicrograph of a transverse cross-section of a weld with a nickel plating of 1000 microinches in shown in Figure 12. Voids may be seen in the melted gold in the weld zone. The outgassing of the organic materials used in the gold-plating solution is suspected as the primary contributing factor. A transverse cross-section of a nickel-plated weld, 1500 microinches thick, is shown in Figure 13 and displays acceptable welding. The laminate material under the copper conductor shown in this figure is FR-45.

The welds of Kovar ribbon and electro-solder-plated copper conductor combinations produced more uniform weld strengths than the Kovar ribbon and gold-over-nickel-plated copper conductor combinations. Transverse cross-sections of welds of Kovar ribbon and electro-solder-plated copper conductors are shown in Figures 14, 15, and 16. The photomicrograph in Figure 14 is of a weld of electro-solder plating of approximately 500 microinches thick over copper conductor on G-10 laminate. The electro-solder plating shown in Figure 15 is approximately 750 microinches thick over copper conductor on Micarta laminate, and the electro-solder plating shown in Figure 16 is approximately 1000 microinches thick over copper conductor on FR-45 laminate. All of the three electro-solder-plating thicknesses produced acceptable weld results. The laminate appearances in the weld zone were about the same for all of the three laminates tested.

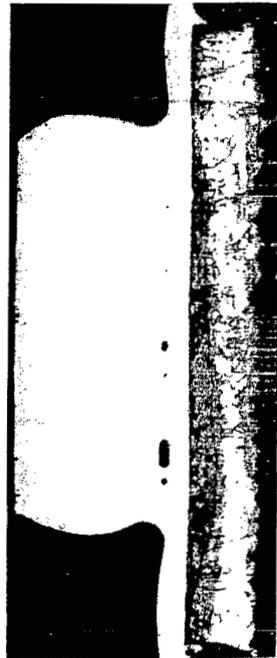


Figure 12. Welded connection with nickel (1000 microinches) over copper conductor (135X).



Figure 13. Acceptable welded connection of gold-over-nickel plating, approximately 1500 microinches thick (135X).

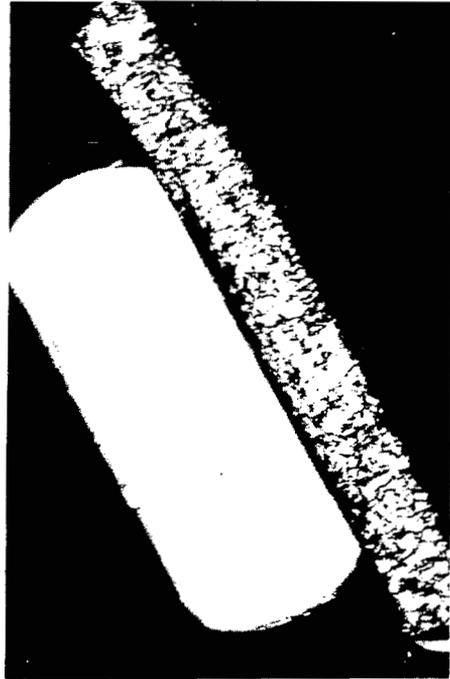


Figure 14. Acceptable welded connection of electroplating (500 microinches) over copper conductor on G-10 laminate (135X).

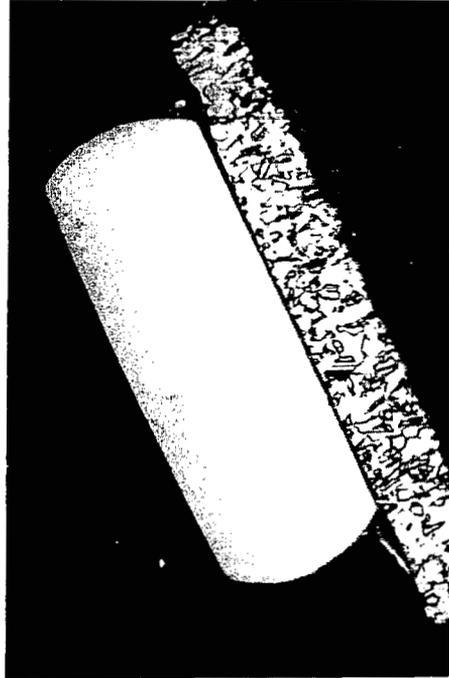


Figure 15. Acceptable welded connection of electroplating (750 microinches) over copper conductor on Micarta laminate (135X).

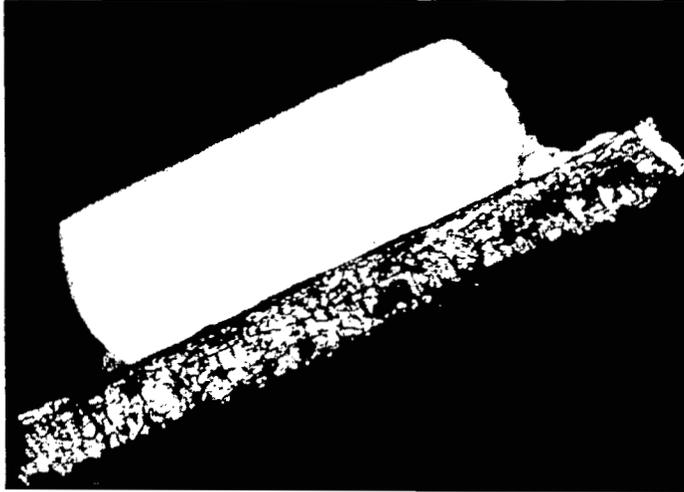


Figure 16. Acceptable welded connection of electroplating (1000 microinches) over copper conductor on FR-45 laminate (135X).

SECTION VIII. CONCLUSIONS AND RECOMMENDATIONS

A. Conclusions

The concluded remarks are as follows:

1. Parallel gap welding of Kovar to copper is feasible but is dependent upon platings used and their thicknesses.
2. Electroplating over copper conductors produced more consistent weld strengths than the nickel-plated copper conductors.
3. A thinner thickness of electroplating can be tolerated better than nickel plating. All electroplating thicknesses investigated produced satisfactory bond.
4. The three laminates used for this investigation were acceptable and revealed similar conditions in the weld heat affected zone. All exhibited a very slight melting of the copper-to-laminate adhesive similar to that seen in parallel gap welding Kovar ribbons to Kovar conductor printed wiring boards.
5. The outgassing of suspected occluded organic materials used in the gold-plating solution is suspected to be the cause of blistering experienced adjacent to the welds and the voids in the weld zone on gold-over-nickel-plated copper conductors.

6. Kovar ribbon and copper conductor size combinations within the scope of this investigation did not appreciably affect the quality of the welds.

B. Recommendations

The recommendations are as follows:

1. Solder-platings/coatings over copper conductors are recommended.
2. All solder platings/coatings must be uniform in thickness and in density.
3. Solder plating must be 63/37 or 60/40 and fused in suitable hot oil.
4. Parallel gap welding to bare, gold-plated, or gold-over-nickel-plated copper is not recommended.
5. All Kovar ribbons shall be gold plated.

George C. Marshall Space Flight Center
National Aeronautics and Space Administration
Marshall Space Flight Center, Alabama 35812, June 22, 1970
933-50-07-0300

APPENDIX A

STATISTICAL ANALYSIS OF TEST RESULTS

Since the primary mode of failure of the welds by the peel-pull test method was through tearing and lifting of the copper from its substrate, rather than failure in the welds, the statistical effects of plating type of thickness on weld strength essentially were not determined in this experiment. The most important variable then would appear to be bond strength of the copper to its substrate which may vary with the type of board material and its adhesive characteristics. To test the hypothesis that there is no effect caused by plating, board material, and interaction between them (null hypothesis), an Analysis of Variance (ANOVA) was conducted using data obtained from 1000-microinch nickel and solder on all three board materials. Data from this ANOVA are presented in Table A-1. The comparison of F values, calculated with those from statistical tables for the F distribution, indicates that we can reject the hypothesis with 99-percent confidence; that is, the board material, platings, and their interactions have an effect on the peel strength of copper from the substrates. The effects of plating on peel strength can be explained by the fact that they increase the strength of the copper conductor and thus increase its resistance to tearing and bending during the peel test.

To determine if the peel strengths of any one combination of board material, plating type, or thickness is significantly greater than any other combination, the means of the peel strength data can be compared. This was performed using Student's "t" distribution, with the unbiased estimate of the standard deviation (\hat{S}), calculated in the ANOVA, the means (\bar{X}) and standard deviations of peel strength. Data are given in Table A-2 for the individual levels of the factors tested, as well as overall means ($\bar{\bar{X}}$) for combinations of platings, thickness, or board materials. To test the hypothesis, at a confidence level of 99 percent, that one mean is significantly different from another, the following expression is used:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\hat{S} \sqrt{2/N}}$$

where

\bar{X}_1 and \bar{X}_2 are the means to be compared

$N = N_1 = N_2 =$ sample size

$\hat{S} =$ Standard deviation for error = 0.245.

The critical value for t_{99} with degrees of freedom of 98 = 2.63. An example calculation

TABLE A-1. ANALYSIS OF VARIANCE OF PEEL STRENGTH DATA FOR 100 MICROINCHES OF NICKEL AND SOLDER

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Square	F _{cal}	F ₉₉
Board Material	5.23	2	2.62	43.66	4.69
Plating	0.51	1	0.51	8.50	6.73
Interaction - Board Material x Plating	7.28	2	3.64	60.66	4.69
Error	17.98	294	0.06		
Total	31.00	299			

TABLE A-2. MEANS OF PEEL STRENGTHS AND STANDARD DEVIATIONS (S) CALCULATED FROM RESULTS OF PEEL TESTS

Board Material	Nickel (μ in.)		\bar{X}_{Ni}	Solder (μ in.)			\bar{X}_{solder}	\bar{X} Board Material
	1000	1500		500	750	1000		
G-10	(0.25) 2.32	(0.28) 2.51	2.41	(0.12) 2.53	(0.18) 2.28	(0.17) 2.35	2.39	2.40
FR-45	(0.42) 1.90	(0.22) 2.02	1.96	(0.15) 2.13	(0.13) 2.03	(0.17) 2.06	2.07	2.03
Micarta	(0.38) 2.12	(0.32) 3.03	2.57	(0.14) 2.18	(0.17) 2.10	(0.19) 2.18	2.15	2.32
\bar{X}	2.11	2.52	2.31	2.28	2.14	2.20	2.20	2.25

for comparison of the means for 1000 microinches nickel on FR-45 board material (1.90 pounds) and 1000 microinches solder on G-10 (2.39 pounds) is as follows:

$$t = \frac{2.39 - 1.90}{0.245 \sqrt{2/50}} = \frac{0.49}{0.49}$$
$$= 1.00 \quad .$$

Since the calculated value for t (1.00) is less than the critical value for t (2.63), there is no significant difference in these two means at a confidence level of 99 percent. Similar calculations performed on the means for all combinations of board material, plating, and thickness likewise showed no significant differences in their effect on peel strength of the welded joints. However, "t" tests for comparison of the grand means (\bar{X}) for both the different board materials as well as plating types, using the appropriate "N" for sample size and degrees of freedom, showed a significant difference in all comparisons. Thus, the mean for G-10 material is significantly greater than for the other two and the mean for nickel is greater than for solder.

Based on statistical analysis of the data, the greatest peel strength overall was obtained with nickel platings and G-10 board material. However, based on the lower standard deviations and ranges for solder and considerations of more universal application, the use of solder plating from 500 to 1000 microinches thickness on G-10 is recommended.

APPENDIX B

QUALITY ASSURANCE AND INSPECTION CRITERIA

To perform acceptable welding with repeatable results, adherence to definite parameters and process controls is mandatory. The requirements outlined in the following paragraphs will aid in producing and determining acceptable welds.

1. Weld System

The power supply must possess the capability of consistent performance at manually selected pulse amplitude (voltage) and at the selected pulse duration (time). Meters must be provided to detect any variance from these selected parameters.

The weld head shall possess the capability of repeatably applying a preselected force to the work pieces, and permit manual adjustment of the electrodes. A means of automatically discharging the weld pulse after applying the selected electrode force must be provided.

2. Materials

- a. Kovar ribbons must be gold-plated, performed, and cut to proper lengths prior to usage.
- b. All materials must be thoroughly cleaned by accepted methods just prior to welding.
- c. Solder shall be Sn60 or Sn63 and fused in suitable oil when electrosolder plating is used.

3. Welding Operation

To assure that quality welding is accomplished, the following guidelines are recommended:

- a. Prior to production welding, verification of selected welding parameters shall be conducted on similar Kovar ribbon and printed wiring board materials.
- b. Pull test five welds using a 180-degree peel-pull method with a suitable tool. The weld shall be considered acceptable when a portion of the copper conductor material adheres to the Kovar ribbon and the conductor does not exhibit blowholes of excessive melting.

c. The electrode tips shall be kept clean and free of contaminants. The tips must be flat and exhibit no mushrooming.

NOTE

Use a slight overpressure of the electrodes rather than underpressure as this will result in a more uniform resistance of materials in the electrode contact areas.

4. Weld Inspection Criteria

All welds shall be visually inspected at 30X. Where positive identification of weld condition is necessary, greater magnification may be used.

Visual acceptance criteria are as follows:

- a. Weld shall exhibit a darkened gold band of approximately 70 percent of the lead area between the electrodes.
- b. Weld shall exhibit a smooth fillet along ribbon conductor interface in the weld zone.
- c. A solder fillet shall extend beyond the electrode tip thicknesses along the ribbon length.
- d. The Kovar ribbon shall be fully supported by the conductor.

The following weld conditions shall be cause for rejection:

- a. Open weld – An open weld is where welding has been attempted but no bonding of the materials has occurred or where a weld is required but overlooked by the operator.
- b. Cracked weld – A weld that exhibits a crack or a separation.
- c. Blowhole – A weld in which holes or voids are evidenced.
- d. Deformed weld, excessive melting – A weld in which either the ribbon or the conductor material has been reduced by 15 percent or more.
- e. Surface fusion – A weld with surface of the lead at ribbon-electrode interface exhibiting fusion or melting.
- f. Weld alignment – A weld with portion of ribbon extending beyond weld pad dimensions.

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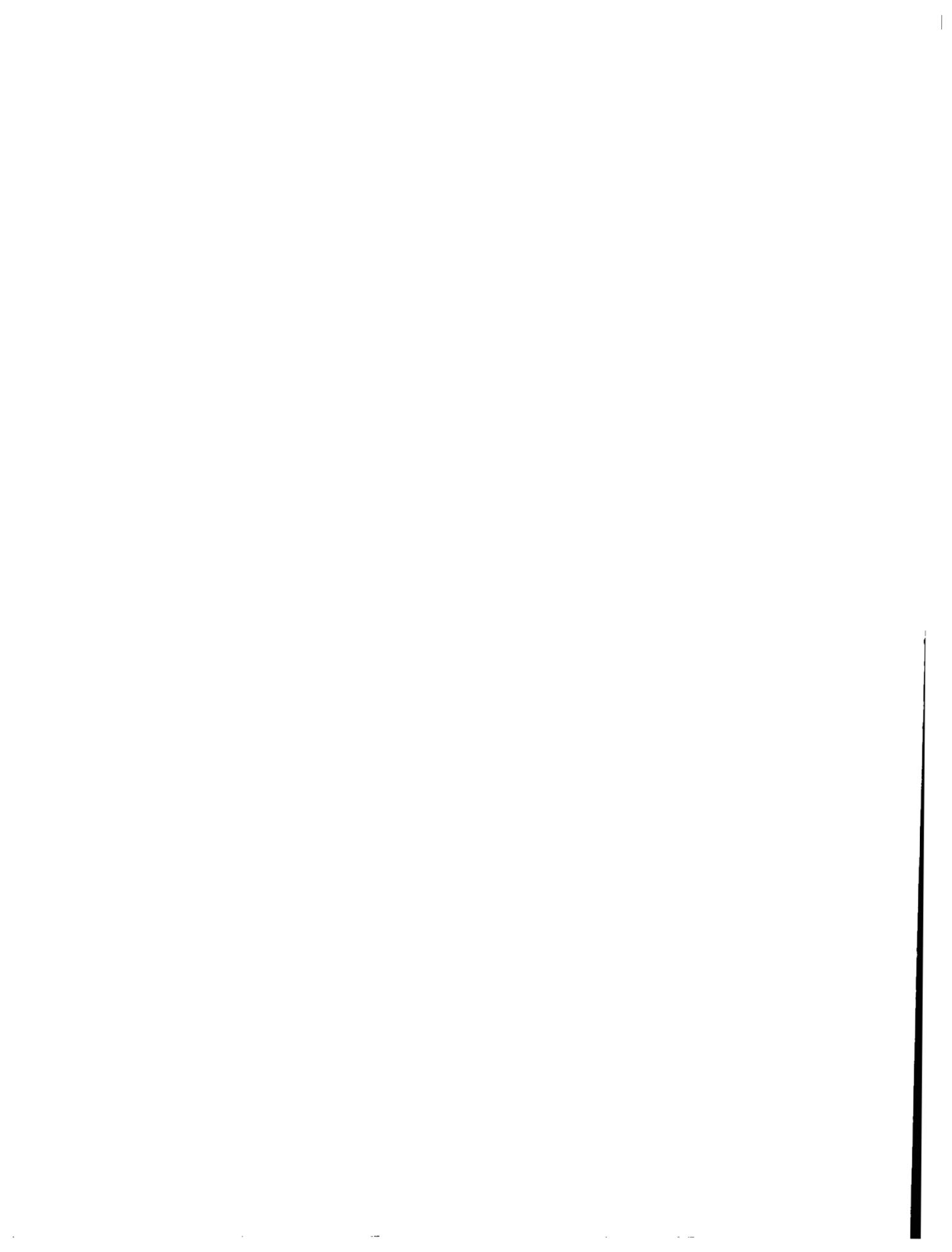
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